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Detailed image of fractures activated by a fluid injection in a producing Indonesian geothermal field

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We used several data-processing techniques to analyze 237 earthquakes in order to study a water injection experiment in a geothermal field in Indonesia. We calculated an optimal *a-priori* one-dimensional crustal model by inverting the entire set of *P*- and *S*-wave arrival time measurements. The relocated earthquakes formed a tight cluster near the bottom of the injection well. These locations provide the best estimate of the absolute location of the cluster.

We computed relative hypocenter locations from arrival-time differences using the program *hypocc*, which spectacularly improved the clustering of the locations. The earthquakes defined a planar structure striking N 50˚ E and dipping 70˚ to the NW. It was ~ 400 m long (along strike) and ~ 400 m high (down dip).

We derived moment tensors for 38 earthquakes by inverting body-wave amplitude ratios. Most had large explosive components and were consistent with combined tensile crack opening and shear. Most were consistent with both components responding to the same stress field, but a significant number, including some of the largest earthquakes, required different orientations for the stress fields, corresponding to the opening and shear components. A component of fluid inflow into the newly formed crack at the moment of rupture is also required to fit the data.

A joint interpretation of the results provides a detailed picture of the effect of water injection into the well. The water flowed into a pre-existing fault zone, part of which was activated seismically by a tiny foreshock followed immediately by a large M 3.3 earthquake. This large earthquake affected some tens of metres of the fault, causing opening at the millimetre level, combined with shear slip. Failure in this mode then propagated out over a ~ 400 x 400-m plane via many more smaller earthquakes. The activated plane represents part of a more extensive fault zone.